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Measurement results and experiences from an energy renovation of a typical Danish single-family house

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SUMMARY:
Energy renovation of existing buildings has a large potential for cost effective energy savings. However, it is a major challenge to develop and implement the technologies for reducing the energy use in existing buildings to a very low level in combination with renovation of the buildings. To demonstrate how it could be done in small residential buildings a thorough retrofitting of a single-family house from 1972 was carried out. The house was brought up to the energy performance level of a new house. The energy renovation has reduced the net room heating consumption from 27.8 to 12.7 MWh/year corresponding to a 54 % reduction. The energy renovation project has proven that it is possible to renovate a typical Danish single-family house from the 1960/70's in a cost efficient manner to roughly the energy performance standard of a new Danish single-family house. As a positive side effect the living conditions have been greatly improved. In the paper the author also describes the lessons learned during the process of renovating the house.

1. Introduction

In 2006, new tighter energy performance requirements were introduced in Denmark for both new buildings and renovation. These requirements are based on the directive on Energy Performance of Buildings, the EPBD (2002/91/EC), but the Danish government has desided to implement renovation requirements to all building and not only buildings larger than 1000 m^2 as required in the EPBD directive. In general the effect of the new requirements for renovation is that existing buildings should be brought up to the energy performance level of new buildings in connection with larger renovations and other substantial changes in the buildings.

Studies (Tommerup 2004, Tommerup 2008) have documented that energy optimization has to be done in connection with traditional maintenance and other improvements/changes of the building in order to be cost-effective. Furthermore it has been pointed out that such opportunities for thorough improvements of the building envelope and technical installations occur with a long interval so it is of outmost importance not to miss these opportunities by making a renovation without upgrading the energy performance of the specific building component; i.e. for instance bringing the insulation standard of the roof up to and preferably beyond the current requirements in the building code.

The overall purpose of the demo-project has been to demonstrate that is it technically possible to bring a single-family house up to current energy standard of new buildings. In most cases this would imply a step by step approach. The components would be upgraded in accordance with the need for renovation or maintenance. This might be over the next 10-15 years. For a demonstration purpose this is not suitable. Thus the renovation tasks and following energy optimization have been forced. Due to this the costs of this project should not be taken as guidance for costs in general for energy upgrade of existing buildings.

To demonstrate how it could be done in single family residential buildings, a thorough energy efficient renovation of a typical Danish single-family house from the 1960/70's with need of renovation was initiated by Rockwool International in 2005. The house is typical as about 500,000 of a total of 1.1 million Danish detached single-family houses were erected in the 1960/70's.

The project is a follow-up on an energy renovation project regarding an old poorly insulated single-family house built in 1927 that was carried out a few years ago. This project showed that large profitable energy savings are possible (Overgaard 2005). Preliminary results (Tommerup 2007) have indicated that it is achievable to renovate the typical Danish single-family house from the 1960/70's to roughly the energy performance standard of a new Danish single-family house and that living conditions are expected to be greatly improved. The present paper presents results from a whole year of measurements before and after the renovation, which generally verify the preliminary conclusions. The lessons learned during the process of renovating the house are described, taking into account to some extent the twofold benefit of renovation, i.e. the energy savings and the rehabilitation of the physical condition of the building elements.

2. House before the renovation

The selected house was built in 1972 and is occupied by a small family of three (two adults and their teenage son plus three dogs), and has a heated floor area of 155 m^2 and a volume of 400 m^3. It should be noted that the Danish way of calculating the heated floor area is to use external dimensions, which is different from most other European countries who use internal dimensions. To convert e.g. energy consumption per external squaremeters into internal dimensions an approximate multiplying factor of 1.25 could be used.

The one storey house consists of a large living and dining room area with a ceiling to the ridge, three small living rooms, a kitchen, bathroom, toilet, entrance hall and utility room. Some illustrations showing the house before the renovation are shown in Fig. 1 below.

Exterior wall structures of the house consisted partly of 300 mm insulated cavity walls (around 75 mm of insulation) with steel ties and with an outer leaf of 110 mm masonry and an inner leaf of 100 mm light-weight concrete or 110 mm masonry. Parts of the external walls were originally framed walls with studs of timber and with an insulation thickness of 75 mm, which was later increased by 125 mm. The fairly large areas of windows were traditional old wooden windows with double-pane glazing.

The roof with one half of it having a ceiling to the ridge and the other half with a normal flat ceiling was insulated with 100 mm and 300 mm of mineral wool, respectively. The slab on ground construction had an insulation thickness of only 30-50 mm.

Fig. 1. North and south facing façades and the ceiling to the ridge in the living room

Room heating was provided by iron heaters with old thermostatic valves. The room heating system was water-based, pump-driven, and two-stringed. The heating was produced by a 15-year-old traditional open gas boiler placed in the utility room (supplemented by a wood burning stove). Domestic Hot Water (DHW) was stored in a 90 l integrated hot water tank. The heating pipes were placed in the insulation layer of the slab on ground construction.

The necessary ventilation (i.e. fresh air supply) in the house was provided by means of manual opening and closing of windows combined with use of air shafts in external walls and roof (i.e. natural ventilation). Besides this intended and somewhat controllable ventilation, a significant and uncontrolled infiltration took place through various air leakages in the building envelope.

3. House after the renovation - energy saving measures carried out

Specific solutions were designed for renovation of roof, external walls, foundation, windows, heating system and ventilation system. The implemented energy saving measures carried out on site were:

- External insulation of walls (100-150 mm)
- External insulation of foundations, 45 cm below ground (100-225 mm)
- External insulation of the ceiling to the ridge (345 mm) (no extra insulation of the flat part)
- New slim framed wooden windows and external doors with double-pane low-e-glazing

- New triple-pane low-e-glazing with krypton in the large glazing facades
- Air tightness measures regarding building envelope
- New high-efficiency condensing gas boiler (Viessmann Vitodens 300), insulated hot-water tank and new thermostatic valves.
- Installation of a mechanical ventilation system with high-efficiency heat recovery (Nilan Comfort 300T EC)

Fig. 2 shows a cross section of the house and the external envelope related improvements. The external insulation of the exterior walls increases the heated floor area from 155 to 161 m^2. Insulation of the poorly insulated slab on ground construction was, due to the economic implications, not prioritized as one of the measures carried out.

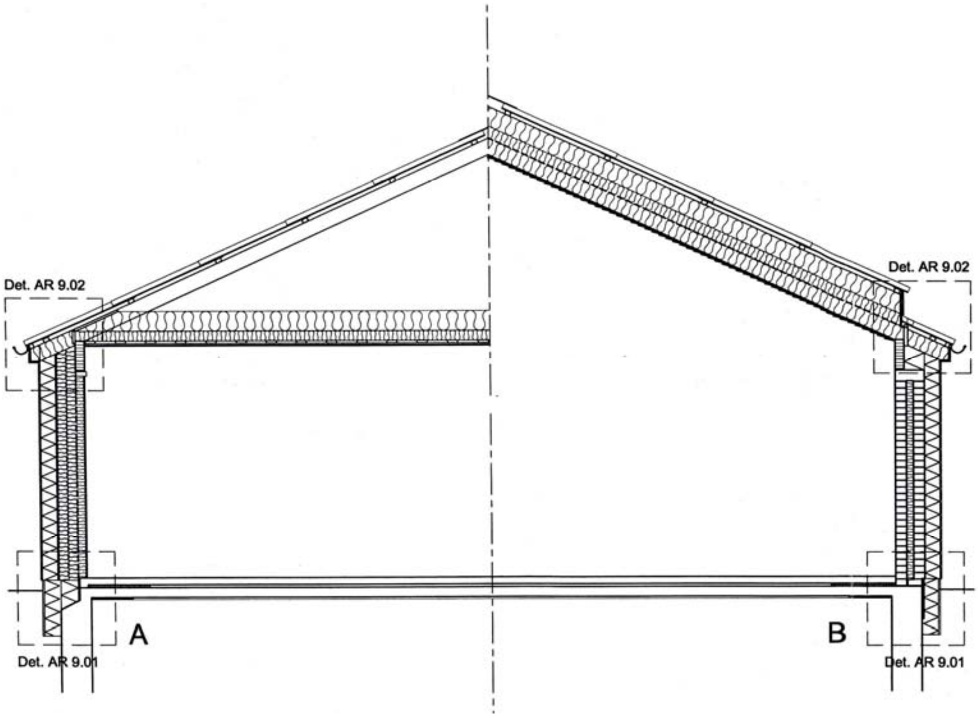

Fig. 2. Cross section of the energy renovated house

Fig. 3 shows the façade of the house. Note the new rain screen, the new slim framed wooden windows, new doors, the external insulation of the ceiling to the ridge (left side), and the outlet from the condensing gas boiler. The appearance of the façades after the energy renovation must be rated as a considerable so-called non energy benefit.

Fig. 3. House façade to the south after the renovation.

4. Measured energy consumption and indoor environment before and after the renovation

A detailed monitoring program was implemented in order to document the energy performance and indoor climate before and after the renovation, which included measurements of energy consumptions, air change rates using blower door and tracer gas methods, indoor climate conditions and solar radiation. The measurements started in June 2005. This paper is based on measurements carried out from September 1st 2005 to January 31st 2008. The renovation took place in November and December 2006.

4.1 Temperatures

The measured indoor temperature level was approximately 2˚C higher after the renovation (21.9˚C compared to 20.1˚C), which is based on measurements in the heating season and at the same time of the year, i.e. the month of January and February, see Fig. 4.

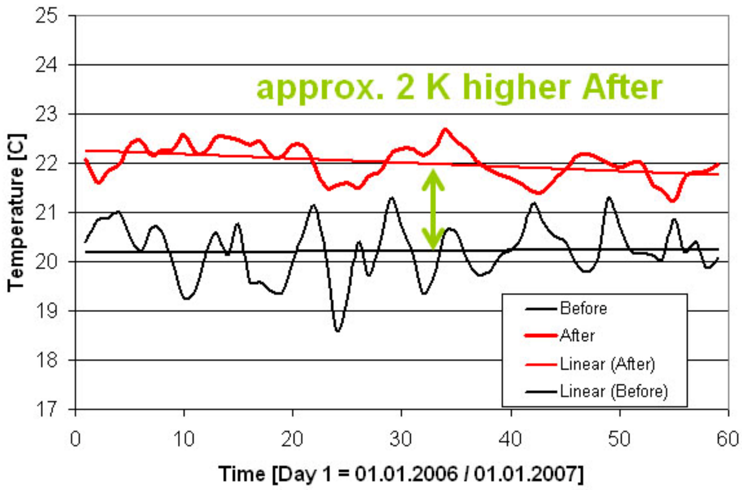

Fig. 4. Average indoor temperatures during January and February 2006 (Before) and 2007 (After).

Fig. 4 clearly shows that the energy renovation has greatly improved the thermal indoor comfort. The average indoor temperature rose from about 20 to 22˚C. Before the renovation the temperature fluctuated between 18.5 and 21.5˚C (3 K) and after the renovation the variation was only 1 K. Before the renovation the resident had problems with heating up the house during cold winter days, and that is certainly not the case after the renovation. The higher temperature level after the renovation has its drawbacks as it results in higher energy consumption for space heating compared with a situation with unchanged temperature conditions.

4.2 Air change rates

The air leakage of the building before and after the renovation was measured by means of *a blower door test at 50 Pa* pressure difference between inside and outside. Before the energy renovation the house was characterised by having no mechanical ventilation and a rather leaky building envelope corresponding to an air leakage rate of 12 ach at 50 Pa (ach is an abbreviation for air change per hour). The blower door test result was reduced significantly to 2.1 ach after the renovation. This level of air leakage corresponds roughly to the level of air thightness required for new Danish buildings at 50 Pa, which is 1.5 l/s/m^2 or 2.2 ach.

The air change rates *at normal use* of the house were measured during the month of November 2005 by means of tracer gas measurements. The PFT-method (Bergsøe 2007) and also CO_2-measurements (Baránková 2007) were used. The average ventilation rate at normal use was measured at 0.39 ach by means of the PFT-method and the CO_2 measurements showed a variable air change in the different rooms of 0.19 - 0.46 ach corresponding to an average of 0.3 ach. The measured level of air change rate of 0.3 - 0.4 ach before the renovation is slightly lower than the typical design value of 0.5 ach.

The energy renovation included the installation of a mechanical ventilation system with heat recovery. The air change rate at normal use after the renovation was measured early 2007 but only by means of the PFT-method, and it showed a total air change rate of 0.51 ach including infiltration. The pre-adjusted ventilation air flow rate was 0.45 ach, so the small difference (0.06 ach) is an indication of the post renovation infiltration air change rate at normal use.

4.3 Gross energy consumption for heating before and after

In Denmark all legislation and standards are based on requirements to the gross energy performance of the building as mentioned before. Results in this chapter are therefore based on this.

The total energy consumption for heating (m^3 per year) has been continuously measured from June 2005 and until now. The yearly consumption is compared before and after the renovation. The consumption in the renovation period is influenced by the renovation and is left out of the comparison.

In the table below the preliminary results of the measurements are shown. In the coming month the results will be further investigated and a final report of the project can be expected by the end of the year.

Table 1 Preliminary results of the project. These results show a reduction of the heating consumption of 54% due to the energy renovation of the house.

	Before 1. September 05 – 31. August 06	After 1. February 07 - 31. January 08
Gas consumption, m^3	2717	1610
Fire wood (estimate), m^3	4 $m^3 \approx$ 455 m^3 gas	0 (not used in the heating season)
Total equivalent gas consumption, m^3	3172	1610
Yearly boiler efficiency	85 % (estimated)	98 % (energy labelling)
Gross energy consumption for heating, m^3	2696	1578
Gross energy consumption for heating, MWh/year	29.7	17.7
Estimate of gross domestic hot water consumption based on consumption in the month of may, MWh/year	$12 \cdot 0.25 = 3.0$	$12 \cdot 0.45 = 5.4$
Net room heating consumption, MWh/year	26.7	12.3
Number of degree days in the measurement period	3126	2632
Number of degree days in a standard year	3258	3258
Net room heating consumption adjusted for degree days, MWh/year	27.8	15.2
Ajustment for higher indoor temperatures, MWh/year	0	- 2.5
Adjusted net room heating consumption, MWh/year	27.8	12.7
Result		Reduction 54 %

Comments to the table:

- The house owners were asked not to use the fire stove in the measurement period after the renovation
- The energy consumption for hot water production is estimated to 12 times the consumption in the month of May which is assumed to be a relatively normal working month with no consumption for heating. It is assumed that the hot water consumption is the same all year. The estimate of hot water

consumption including heat losses included estimation of the summer efficiency of the boiler. The final documentation of the project will include more detailed investigations of the variations in the boiler efficiency during a year.
- The use of degree days is a relatively simple way of adjustment of the data. In connection with the further investigations it will be judged whether this is sufficient or if more advanced methods (including adjustment for solar gains) should be used in the final documentation of the project.
- The temperatures (January and February) in the house have increased 2 degrees. This indicates that the family has achieved an increase in indoor comfort but it also means that the energy consumption is higher in the situation after the renovation than before. To compare the achievements the results in the "after" situation has been adjusted. The adjustment is based on a simulation carried out using the Danish building simulation tool BSIM (BSIM 2000-2008).
- Electricity consumption has been measured but not yet been evaluated. This will be discussed in the final report.
- The energy consumption for hot water production has increased since there has been installed a circulation pump for hot water for comfort reasons. Since the hot water pipes run in the insulation layer under the concrete slabe under the house only a very small part of the heat loss from the pipes actually add to the heating of the house. In the calculation above it is assumed that none of the heat loss add to the heating of the building.

5. Economy

The total installed costs of the renovation have been approximately kr. 900,000 (Euro 120,000). As mentioned in the introduction the aim of the project has been to demonstrate the technical possibilities for upgrading the energy standard of such buildings to current standard in the building code. Thus several tasks of maintenance have been forced. It should also be noted that the refurbishing was done in a period with rather high activity in the building sector resulting in higher costs. This would probably be lower today. The cost should be split into costs for maintenance and other building improvements done without energy optimization, and the costs for bringing the energy standard up to current level. A correct image of this requires two cases to compare. This has not been possible in this project so the only indication is the subjective estimate of the contractors who have made the estimate that approximately ½ of the costs can be referred to energy improvements. This subject will be further investigated before the final report is issued. At this point it has to be stressed that the implementation of the requirements to energy renovation in the building codes should lead to a bigger market for energy optimization thus lowering the prices as it becomes more common and due to development of new solutions which can also lower the costs.

The energy savings are expected to lower the family's energy bill by about 20,000 DKK/year (2,700 €/year) using an energy price of 850 DKK/MWh (115 €/MWh). That equals a pay back time of 25 years.

With a conservative estimate of a rise in energy prices of about 2% per year, the running yearly energy savings of the energy measures will be equal to the yearly interest and capital repayments for the house owner. In case of increasing energy prices the economy of the house owner will be positive. The same is assumed for the value of the house. The aesthetics have been modernized and increasing energy prices should also improve the value of the house on the market as the energy performance of the house and hereby the energy expenses now and in the years to come are better than for similar houses.

6. General experiences during the renovation process

The general impression of the project is that it is possible to reduce the energy consumption and at the same time improve the indoor comfort and the architechture of the house. The best solution for insulation of the house is to insulate the outside, since this prevents moisture problems and more effectively eliminate thermal bridges. This house was therefore insulated from outside. The lessons learned during the process of renovating the house were:

- The premise for refurbishing the house was that the aesthetic value of the house was retained or even improved. In this case this could easily be done since the roof had a large overhang. In other cases with less overhang this could have caused severe aesthetical and practical problems.

- It was the goal to insulate with the most economic thickness of insulation – in praxis the thickness was governed by practical reasons as you were working on an existing house. It is important when only parts of buildings are changed/renovated to take the further step into account – i.e. to think about the wall insulation when the roof is changed.

- Local restrictions on facades can cause exemptions to change the outlook of the facades. (e.g. demands of the appearance of facades, demands for material used). To get such exemptions depends usually of the local houseowners' association and/or the building authority. The new Danish building code from 2008 includes the possibility to install insulation externally on building facades without any further permission.

- Using a ventilation system with heat recovery requires a very air tight house, which again requires a very good workmanship placing and taping the vapour retarder especially under wet weather conditions. Furthermore the loft in half of the house had to be sealed which was done by adding a plasterboard ceiling.

- It was difficult to get the right data for the ventilation system, and it seems that there is a need for more systematic and reliable information of the efficiency of these small systems.

- The airtightness of the building has been improved dramatically and the building now full fills the same requirements as to new buildings. Generally this is very good news since energy losses trough ventilation becomes a great factor when other parts of the building are improved.

- Doing perimeter insulation was only possible to a depth of 250 – 300 mm, as the trench footing from this level was poured without scaffolding.

- Insulation of slab on ground construction was not feasible or reasonable for economic reasons. Existing concrete floor would have to be removed and excavation for new insulation to be done including a new floor construction and placement of new heating pipes on the warm side of the building envelope.

- Even though drawings exist for the house a lot of investigations have to be done to verify these drawings. The experience from the refurbishing was that drawings did not always correspond to existing conditions.

7. Conclusions

1. The project has documented that it is possible to lower the energy consumption in a house typical for the 500,000 one family houses from the 60-70'ies to a level corresponding to new buildings.
2. The energy renovation has reduced the net room heating consumption from 27.8 to 12.7 MWh/year (a 54 % reduction). The energy savings are expected to lower the family's energy bill by about 20,000 DKK/year (2.700 €/year) using an energy price of 850 DKK/MWh (115 €/MWh).
3. Total installed costs of the renovation (including both upgrading/refurbishment and energy saving measures) were approximately 900,000 DKK (120,000 €). It has to be taken into consideration that the project due to demonstration purposes has forced a number of investments and that the project was done in a period with very high activity in the building sector and thus considerable increases in prices. It is not easy to split the price of the energy upgrade from the general upgrade of the building. This topic has not yet been investigated.
4. With a conservative estimate of a rise in energyprices of about 2% per year, the running yearly energy savings of the energy measures will be equal to the yearly interest and capital repayments for the house owner.
5. As a positive side effect the living conditions have been greatly improved: much better thermal indoor climate, more uniform ventilation air change rate and no cold draught, and acoustic improvements, especially reduced noise from outside.
6. To further improve the energy performance of the house the most obvious measure is to remove the floor concrete slab and carry out a highly insulated floor heated construction with a suitable weather controlled supply-pipe temperature. Use of solar energy for DHW and supplement for room heating is

another obvious measure that could be considered in the future development of low energy solutions for renovation of existing single-family house.

8. Acknowledgements

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